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## RELATION BETWEEN THE ANNUAL PRECIPITATION AND THE NUMBER OF HEAD OF STOCK GRAZED PER SQUARE MILE.

By J. WARREN SMITH, Meteorologist.  
(Washington, D. C., June 30, 1920.)

### SYNOPSIS.

In the Great Plains States the relation between the annual precipitation and the number of head of stock that can be grazed per square mile can be fairly well established, the possible number decreasing with fair uniformity from east to west with the decreasing annual rainfall. The number grazed in Oklahoma and Texas is close to 50 per square mile where the rainfall is between 25 and 35 inches and about 40 where the rainfall is from 15 to 25 inches.

In the Great Plains States north of Oklahoma where feeding is necessary during the wintertime and where the rate of evaporation is less in the summer months, the grazing rate averages close to 20 where the rainfall is between 10 and 15 inches, nearly 40 where it is from 15 to 20 inches, and nearly 80 where it is 20 to 25 inches. The ratio rises at a faster rate with heavier rainfall.

In all the Rocky Mountain region it becomes more difficult to establish a ratio between the annual precipitation and rate of grazing because of seasonal distribution of precipitation, temperature variations, the topography, soil, evaporation, snow cover, nature of the vegetation, and differences in the length of the grazing period. In the central and upper Rockies the grazing rate is slightly greater with small rainfall amounts than farther east because of the shorter grazing period, but less than in the Great Plains with heavier precipitation because of the relatively less grazing areas in the higher mountains where the greatest precipitation occurs.

In a study of the climatic control of Australian production<sup>1</sup> the following statement appears:

As regards the three commodities under discussion (wheat, cattle, and sheep), the chief control is undoubtedly that of rainfall. This affects absolutely the distribution of wheat and notably that of cattle and sheep. However, although it is true that no cattle or sheep are found in the desert portion of Australia, yet the flocks and herds range from regions with 60-inch rainfall to those with 6 inches, implying a considerable range of adaptability on the part of the animals concerned. Yet as regards the more important sheep and cattle districts, the rainfall will be shown to define fairly accurately those areas where the pastoral industry seems to flourish best. Moreover, the same isohyets do not affect sheep and cattle equally, and this is another point which will be demonstrated in the maps.

The temperature factor is very important in two of the industries. While cattle are almost ubiquitous and thrive even in the far north and far west, the hot country—or, more exactly, the tropical vegetation—does not appear to suit sheep so well as do the conditions in the cooler and drier regions to the south. The northern limits of the wheat belts are undoubtedly controlled by the increase in temperature.

In Australia, while large numbers of cattle are grazed where the average annual rainfall is between 10 and 20 inches, the best district has a rainfall of 20 to 40 inches a year. Dr. Taylor states that in western Australia the districts having a rainfall of 9 to 12 inches should support 4 cattle to the square mile, while those with a rainfall of 20 to 40 inches should have over 10 to the square mile. In Queensland, only 2 to 3 should be grazed where the rainfall is less than 10 inches.

The sheep occupy the warm inland drier belt and the cattle the wetter coastal regions. The optimum district for sheep is where the rainfall is 20 to 30 inches, except in Queensland where it is 15 to 20 inches. In Queensland where the rainfall is between 10 and 30 inches, 100

sheep to the square mile are grazed. In south Australia the 7-inch isohyet divides the districts of more than 10 and less than 10 sheep to the square mile.

In New South Wales, west of the divide, where the rainfall is between 20 and 30 inches, 250 sheep are grazed to the square mile: where it is between 10 and 20 inches 100, and where under 10 inches only 40 to the square mile on an average. In Victoria the optimum sheep district is where the rainfall is between 20 and 30 inches, while the 15-inch isohyet is the western limit of 100 to the square mile. In Tasmania the principal sheep grazing regions have an average rainfall of 20 to 30 inches.

It is well known in Europe that 1 acre of really good pasture land will support a cow, although in general it is customary to allow 4 acres. It is considered there that where more than 4 acres is necessary to support one cow the pasture should be devoted to sheep.

In the United States, the stock capacity of pastures and ranges depends not only upon the annual precipitation but on its seasonal distribution, as well as on the evaporation, snow cover, and the length of the grazing period, the last three depending largely upon the temperature.\*

On the irrigated lands of the Northwest the stock-carrying capacity of 1 acre of well-established pasture should be not less than 2 cows, or their equivalent in other live stock, under favorable conditions and with proper care.<sup>2</sup> This is at the rate of 1,280 per section or square mile, but it is under irrigation in well-established pasture that has been given the best of care.

In the bluegrass region of central and eastern Kentucky and adjoining districts, 22 of the best pasture fields, totaling 4,237 acres, grazed 1,328 head of cattle, or an average of 3.2 acres per head, equivalent to 200 per square mile. These were the best pastures and do not include steep wooded mountains or rocky lands.<sup>3</sup> The average annual rainfall in this region is from 40 to over 50 inches, and the winters are mild enough to allow for grazing most of the year.

On the bluegrass pastures in the eastern third of Kansas, where the average annual precipitation is between 30 and 40 inches, the practice is to allow about 4 acres to each steer, or at the rate of 160 steers to a square mile. In the western third of the State, where the precipitation averages from 16 to 20 inches, the usual allowance is 10 acres to the steer, or 64 to the section. In the central third of the State, where the rainfall is between 20 and 30 inches, the usual pasture lands graze between these two extremes of stock. Considerable roughage is fed in dry seasons and in the winter time.

\*The topography, soil, and nature of the vegetation must also be taken into account.

<sup>2</sup> Irrigated pastures for northern reclamation projects, Bureau of Plant Industry, Bulletin issued July 20, 1916.

<sup>3</sup> The Grazing Industry of the Bluegrass Region, United States Department of Agriculture, Bulletin No. 397, Sept. 20, 1916.

<sup>1</sup> The climatic control of Australian Production, Griffith Taylor, Bulletin 11, Commonwealth Bureau of Meteorology, Melbourne, Australia.

In extreme eastern Nebraska, where the annual rainfall averages from 26 to 33 inches, from 426 to 640 cattle are grazed per section. In the central part of the southern border counties of Nebraska, where the rainfall varies from 25 to 20 inches from east to west, the number of acres required for each steer varies from 2.5 to 6, or from 256 to 107 can be grazed per square mile, the number per section decreasing westward with the rainfall.

In the Sand Hill region of central Nebraska, where the rainfall is from 18 to 22 inches a year, only from 43 to 50 head of cattle are grazed on a square mile of grazing land. In the national forest region of the Sand Hill district of western Nebraska the average head per square mile of grazing land is 50.

The conditions in Nebraska indicate that rainfall is not the only factor in determining the grazing capacity of the land, but that the character of the soil and the temperature are both important.

In the national forest area in South Dakota (District No. 2 of the Forest Service), where the grazing area is about 73 per cent of the total, 30 head are grazed to the square mile on the actual grazing land. The annual rainfall in most of this region is between 15 and 20 inches. This agrees well with the relation in other sections of the State, except that there is a much larger number of stock in proportion to the rainfall in the area of Jackson, Haakon, Lyman, and Stanley Counties in the central-southwest portion, probably due to the better shipping facilities. In general, in that State, where the annual precipitation is between 15 and 20 inches, the stock runs between 20 and 30 to the square mile.

The grazing period in the national forest area in South Dakota is about 6½ months.

In that part of western North Dakota west of the one hundredth meridian, where the annual precipitation is between 15 and 18 inches, the average number of acres for a 2-year-old steer or colt is 10, or 64 to the square mile. This varies from 43 to 128, depending upon the location.

In the Panhandle district of Texas, including 35 counties with a total area of 1,050 square miles, the average area required for each steer is 20 acres. This is at the rate of 32 per square mile. Soil conditions and cultivation reduce the fair to good grazing ground about one-third, thus making the actual grazing ground support close to 48 cattle to the square mile. The rainfall in this region is close to 20 inches, and nearly 70 per cent of the annual precipitation is received from April to September, inclusive. The evaporation in this region from a water surface is close to 45 inches a year, thus making the carrying capacity less than farther north, where the rainfall is the same.

From information obtainable in Oklahoma, it appears that for year-round pasturing on native sod 15 to 20 acres are required per head of cattle or horses and 2 to 2.5 acres per head of sheep or goats on the range lands of the northwestern counties. On the range lands of southwestern Oklahoma 12 to 15 acres are required per head of cattle or horses and 1½ to 2 acres per head of sheep or goats.

This is at the rate of 32 to 43 head of cattle per square mile where the rainfall varies between 15 and 25 inches and from 43 to 53 head where the rainfall is from 25 to 35 inches. Native pastures are grazed throughout the year in this State, with more or less feeding from December to March, depending upon the inclemency of the weather and the character of the preceding growing season.

In the Great Plains States, just discussed, the precipitation decreases with fair uniformity from east to west, so that large areas can be considered in determining the stock-carrying capacity of the ranges.

Over the great mountainous range States farther west, however, the precipitation is so variable within comparatively short distances, due largely to the topographic features, that a study of the relation of rainfall to grazing becomes much more difficult. The seasonal and yearly distribution of the precipitation is very variable also, and a range carrying a good stand of forage one season may be practically bare the next, due to a very light rainfall. Indeed, it is not uncommon to have a series of years with the rainfall materially less than the normal, or a year when from one-half to two-thirds of the total annual precipitation occurs in one month. A heavy rainfall will be followed by a rapid growth of forage, so that a wet month will be followed by a month or more of good feed.

In the central and lower Rocky Mountain States the stock graze at higher elevation in the summertime and are driven to the lower plains and plateaus in the winter. Close grazing during a season may reduce the carrying capacity about two-thirds.

About three-eighths of the grazing lands of New Mexico receive an average annual rainfall of from 10 to 15 inches, another three-eighths receive from 15 to 20 inches, while about one-eighth have over 20 inches and an equal amount less than 10 inches. Cattle are most numerous in the areas receiving from 15 to 20 inches and sheep are quite as numerous in the districts where the annual precipitation averages less than 15 inches.

The higher districts, with precipitation of 15 to 20 inches or more, are principally used for summer ranges, and stock are moved out at the approach of winter.

Over the plains and lower plateau districts where the annual rainfall averages 10 to 15 inches, some 30 to 40 acres are allowed for each head of cattle, horses, or mules, while 6 to 8 acres are allowed each head of sheep or goats. At higher altitudes, where the precipitation averages 15 to 20 inches, the allowance is 20 to 30 acres per head of cattle and 4 to 6 per head of sheep.

This is equal to 16 to 21 head of large stock per square mile with 10 to 15 inches of rainfall and 21 to 32 head where the rainfall averages 15 to 20 inches. These figures are only approximate, however, as the seasons are so variable. With a dry year such as occurred in 1917 and 1918, even 50 to 100 acres may not afford sufficient feed for one head of large stock, and at the lower elevations whole sections may be so barren that they can not be grazed at all.

In the Pecos Valley, in southeastern New Mexico, where the average rainfall is not over 15 inches, it is estimated that 12 head of cattle can be grazed per square mile if the rainfall is normally distributed; that is, about half of the total annual fall coming during the three summer months. In years with only 50 per cent of the normal precipitation the grazing capacity will be reduced nearly one-half. The following table gives a fair estimate of grazing in the Pecos Valley:

Rainfall.	Cattle per square mile.
Normal, 15 inches. ....	12
50 per cent of normal, 7.5 inches. ....	7
75 per cent of normal, 11.2 inches. ....	10
125 per cent of normal, 18.8 inches. ....	14
150 per cent of normal, 22.5 inches. ....	16

In this region the above figures are also applicable to any month from April to November, inclusive: the number of cattle grazed in any month being dependent upon the precipitation of the preceding month. For example while there was more than the normal rainfall in 1916, two-thirds of the total fell in August. The grazing was very poor up to August but was excellent after that month.

Studies of grazing capacity, on the Jornada Range Reserve in southern New Mexico led to the conclusion that the grama grass range will support one cow on 20 to 30 acres, depending upon the acreage of poorer range types which occur within the grass type.<sup>4</sup>

These figures are computed on a yearlong basis, but with the understanding that the number of stock will be reduced to about one-half the yearly average during the season from July to October. The annual rainfall in this region is close to 8 inches.

There are two well-defined rainy seasons in Arizona, one in winter and the other in summer. It follows, therefore, that there are two well-established growing seasons, except at the high altitudes, above about 4,500 feet, where the winters are so cool as to prevent growth. At the lower altitudes a period of dry weather usually occurs in April, May and part of June, during which time growth ceases and the spring annuals dry up.

The seasonal distribution of the scanty rainfall, and the differences in soil, exposure, and altitude, all resulting in a variety of vegetation, makes it difficult to establish a ratio between the rainfall and the stock grazing in this State. The drier areas often support a variety of browse that has a high sustaining power for stock during periods of drought, while the higher ranges with a greater precipitation afford more succulent types of forage which do not stand periods of drought.

In general, however, the following table presents the relation between rainfall and cattle grazing in this State.

Annual rainfall.	Acres required per steer.	Cattle per square mile.
Less than 5 inches.....	Will not support stock	0
5 to 10 inches.....	From 150 acres near 5-inch isohyet to 40 acres near 10-inch isohyet.....	4 to 16
10 to 15 inches.....	40 to 32.....	16 to 20
15 to 20 inches.....	32.....	20
20 to 25 inches.....	30.....	21

The territory with an average annual precipitation of 20 inches or more is nearly all within the National Forests. The carrying capacity in this region is about 30 acres to each cow or steer, although in the most favorable location it may be as low as 20 acres. Horses require a little different type of range, and since they depend to a larger extent upon forage grasses, a greater area is necessary.

Before the dry period of 1891-1894 more than double the safe carrying capacity of the ranges was being grazed over a large part of this State. With this over-grazing and the general shortage of feed and water, 25 per cent to 50 per cent of the stock died during 1891-1894 in many locations.<sup>5</sup>

At the lower altitudes in Arizona where forage production is often scant, 60 to 75 acres should be allowed for each animal, and in addition some provision should be made for a supply of feed to assist in carrying stock through the occasional severe droughts. The writer of Bulletin No. 65 states further that on rather closely grazed

bunch-grass ranges, 25 to 30 acres are necessary for each head of stock, and 15 to 20 acres on the better class of these ranges. Where possible, it has been found advantageous to graze stock on the lower winter ranges from February to June, and on the higher bunch-grass ranges during the remainder of the year.

Good grass foothill pastures of the Santa Rita Range Reserve in southern Arizona have furnished an average of 365 cow-days' feed annually over a period of years on an average of about 14 acres. Each year during the main growing season the number of stock was reduced about 30 per cent below the average for the year, to give vegetation a chance to grow. Otherwise grazing was yearlong. Utilization was closer than can be expected on open ranges.<sup>6</sup>

In Utah the summer grazing ranges are at the higher elevations and the period covered in July, August, and September. The winter snowfall in these summer-range districts is from 50 to 75 inches or more and has an important bearing on the amount of spring and early summer feed. The snow enables the stock, especially sheep, to feed away from running water, hence where the snowfall is normally small a larger acreage for each head must be provided for safety. For these reasons the summer-grazing districts carry many more stock to the square mile with the same annual rainfall, in this State and to the northward, than in the States farther south, and more than the winter ranges in this State.

There is an area in Rich and Cache Counties where there is a good range that requires only 5 acres to the steer during the three summer months, although the average annual rainfall is between 15 and 20 inches only. Other regions farther south with about the same rainfall, require only from 1 to 2 acres for each head of sheep for the summer months. In Piute and western Wayne Counties where the annual rainfall is less than 10 inches, and the snowfall is not so great it requires from 2 to 2.5 acres for each head of sheep. It is estimated in this State that a steer or horse requires about seven times as much territory as one sheep, although this ratio is variable and depends upon the character of the vegetation. The secretary of the National Wool Growers' Association says that about 700 pounds of sheep consume about as much feed as 840 pounds of steer.

If the acreage required for sheep is translated to cattle at a ratio of 1 to 7, we find that the summer ranges in Utah will support from 46 to 73 cattle per square mile during the three months, where the annual precipitation is from 15 to 20 inches or over; from 36 to 46 in parts of the area that receive from 10 inches or slightly less to 15 inches. In the winter range districts, based on the same ratio, a square mile will support from 7 to 10 cattle where the annual precipitation is from 5 to 10 inches, and 16 where it is between 10 and 15 inches. In some sections of the State the figures given above are for actual grazing land which may not be more than one-fourth of the total in the territory.

In the National Forest areas, particularly in Colorado and Wyoming, there is such a variation in the quality and quantity of the forage, as well as in the seasons and the distribution of the precipitation throughout the seasons, that a closely drawn ratio between rainfall and the number of head of stock possible per unit of area is subject to serious question.

Where lands are fenced and the number of stock on particular areas definitely controlled there may be a closer correlation possible. For example, in Lincoln

<sup>4</sup> Increased Cattle Production on Southwestern Ranges, United States Department of Agriculture, Bulletin 588, 1917.

<sup>5</sup> The Grazing Ranges of Arizona, Arizona Experiment Station, Bulletin No. 65, 1910.

<sup>6</sup> Range Management of the National Forests, United States Department of Agriculture, Bulletin 790, 1919.

County in eastern Colorado, it is considered that a section of grama grass land will carry about 50 head of cattle for about 7 months in the average season.

In the National Forest lands in Colorado, however, the average head of stock per square mile of grazing land, in terms of cattle, is 47. The average grazing season for cattle and horses is 6 months and the average sheep season is about 3 months. The ratio between sheep and cattle is 5 to 1. The area of National Forests in Colorado is 14,988,190 acres and about 60 per cent is grazing land. The grazing stock consists of 421,015 cattle and horses and 1,177,190 sheep and goats. The annual precipitation is from 20 to 30 inches in the higher mountains in Colorado and from 15 to 20 inches in the foothills of the forest reservations.

The National Forest lands in District No. 2 in Wyoming cover some 4,019,305 acres, 63 per cent of which is grazing land. The average head of stock on the grazing land, in terms of cattle, per square mile is 45. The average annual rainfall over these districts varies from 15 to 25 inches, with a mean of close to 20 inches. The average cattle and horse grazing season is about 6 months, and the average sheep season is 3 months. Sheep are converted into cattle with the ratio of 5 to 1.

In the Bighorn National Forest, which covers 1,136,200 acres, 99 per cent of which is grazing land, the average head of stock per square mile, in terms of cattle, is 43. The average annual precipitation is from 18 to 22 inches. The Shoshone National Forest covers 1,609,000 acres, only about 34 per cent of which is grazing land. The annual precipitation is between 15 and 25 inches, and the average cattle per square mile of grazing land is 32. The Medicine Bow Forest of 511,382 acres, 34 per cent of which is grazing land, is credited with 80 head of cattle per square mile of grazing land. The annual precipitation is from 15 to 20 inches. The Washakie Forest, of somewhat smaller area, of which 76 per cent is grazing land, carries 45 head of cattle per section of grazing land. The precipitation is 20 to 25 inches. The Hayden Forest, where the average annual precipitation is 15 to 20 inches, is allowed 58 per section. A considerable number of the sheep in this forest use the Routt National Forest in Colorado part of the season, hence the acreage per head is not so representative as on the other forests. The proportion of sheep to cattle is much greater in this area, also, than on the others mentioned above.

The greater difference in the stock grazed, with nearly the same precipitation, in the different forest reserves in Wyoming illustrates the difficulty in establishing a workable relation between the two factors.

Large areas of land in southwestern Wyoming are grazed by Utah stockmen during the 4 months from January to April, inclusive. It is considered that it will take 2 acres per month per sheep and about 6 times that for horses and cattle. This is at the rate of 13 head of cattle per square mile for the grazing season of 4 months. The rainfall in this region varies from nearly 20 inches close to the Utah border to less than 10 inches toward the edge of the Red Desert.

In all of this northern region some feeding must be done, especially of sheep, when the ground is covered with snow.

On the open range in central Wyoming when the average annual rainfall is from slightly less than 10 to slightly over 15 inches a fair grazing average is 15 acres to the sheep, 40 acres to the cow, and 50 acres to the horse. Averages from a considerable number of reports from different sections of the State give the following grazing values: Where the average annual precipitation is less than 15 inches the average grazing of cattle is 19 to the

square mile; where the precipitation is between 15 and 20 inches, 39 head, and where over 20 inches, 52 head.

It is stated that the ranges in Montana will support more stock during the winter than those considerably farther south. One writer states that the local ranges will support a sheep in winter on 5 acres over considerable areas. This will mean from 16 to 20 head of cattle per square mile where the rainfall is from 15 to 20 inches.

A high rolling range on the Lewis and Clark National Forest in Montana supported 1 cow to every 7.37 surface acres, furnishing 2.65 forage acres per cow for a period of 100 days. The annual rainfall in this region is close to 25 inches and the grazing rate is 87 per section for 100 days.

The State of Idaho has a wide difference in the average annual precipitation, from less than 10 inches in the southwest to over 30 inches in the western mountain slopes. The seasonal precipitation is also quite variable; the summer has the least of the four seasons.

Because of this and the further fact that very complete information has been obtained by the section director of the Weather Bureau at Boise, Idaho, the data for the different National Forests in that State will be given a good deal in detail.

Boise National Forest Range: Average annual precipitation, 7 stations, 25.3 inches; elevation of reporting stations, 3,300 to 5,500 feet; carrying capacity per square mile, 16 cattle, 200 to 225 sheep, April 1 to October 15; low range, June 1 to October 15; high range, June 15 to October 15. Range completely stocked with 136,000 sheep and 5,000 cattle.

Caribou National Forest: Precipitation, 3 stations, 14.8 inches; elevation, 5,200 to 6,300 feet; carrying capacity, 20 cattle and 260 sheep. Notes by forest supervisor: "A considerable part of this range is used by sheep and cattle in common. Taking the total forest as a whole and considering all stock handled under permit, each square mile is supporting approximately 20 head of cattle and 260 head of sheep."

Challis National Forest: Annual precipitation, 3 stations, 14.7 inches; elevation of stations, 5,300 to 6,200 feet; season about 6 months; grazing capacity, cattle 12 per square mile; sheep, no data. Note by forest supervisor: "In making an estimate of this kind, large bodies of land must necessarily be included which are incapable of supporting any class of stock. This includes rugged country that is too rough for use by domestic stock as well as large areas of dense timberland which supports absolutely no forage of any value."

Clearwater Forest: Annual precipitation, 1 station, 48.7 inches; elevation, 3,735 feet; carrying capacity, 20 cattle and horses, June 1 to October 31; 200 sheep and goats, June 15 to October 31. Note by forest supervisor: "Owing to timbered conditions this forest is not considered a grazing forest and can never be developed as such. In ordinary range management it is found that horses require about 25 per cent more range space during a given period than is required by cattle, on account of the fact that they are more readily disturbed, travel greater distances and at greater speed. However, they require but little more forage. A band of dry sheep (ewes) will not consume as much forage as a band of ewes with lambs."

Coeur D'Alene Forest: Precipitation, 5 stations, 39.9 inches; elevation of stations, 2,157 to 4,082 feet; carrying capacity, 80 cattle, 6 months; 160 sheep, 4 months. "The National Forests north of the Salmon River are principally important for timber production and not more than 25 per cent of them have any value for grazing.

There is, however, in the aggregate a large acreage of land suitable for sheep grazing and a considerably smaller amount suitable for cattle grazing. The cattle range on the National Forests is found mostly in meadows along the various streams, and the carrying capacity of such areas is comparatively high."

**Idaho Forest:** Precipitation, 5 stations, 24.6 inches; elevation of stations, 2,200 to 5,025 feet; carrying capacity 19 cattle (season not given), 100 sheep from July 1 to September 30. "A great portion of this forest is very steep and rocky, so that cattle and horses can not use it. There are a few tracts on which cattle and horses graze, and these support about 2,000 head, or 40 head to the square mile. The forest is heavily timbered, at a high altitude, and has many prominent rocks and ledges which tend to make the growth of forage plants less abundant."

**Lemhi Forest:** Precipitation, 6 stations, 9.7 inches; elevation of stations, 4,040 to 7,150 feet; carrying capacity, 60 to 70 cattle and horses, July 1 to October 31; 375 sheep (counting lambs), July 1 to September 30. "Ranges outside the forest generally have a considerably lower carrying capacity. Stockmen locally usually estimate that a 640-acre homestead will support about 40 or 45 head of cattle and horses. It will support five or six times as many sheep."

**Minidoka Forest:** Precipitation, 6 stations, 11.0 inches; elevation, 4,550 to 7,600 feet; carrying capacity, 50 cattle and horses, May 1 to October 31; 250 sheep, June to October 31. "Where mixed grazing, that is, both sheep and cattle, there is increased carrying capacity because of the fact that there are certain forage plants more suitable to one class of stock than to others, and where both kinds of stock are grazed on the same area it tends to a more full utilization of the forage crop."

**Nezperce Forest:** Precipitation, 5 stations, 26.0 inches; elevation, 1,397 to 4,000 feet; carrying capacity, 80 cattle, 6 months; 160 sheep, 4 months. Conditions are similar to those on the Cœur d'Alene range.

**Payette Forest:** Precipitation, 4 stations, 24.8 inches; elevation, 3,300 to 5,200 feet; carrying capacity, 25 cattle, 6 months; 100 ewes with lambs, 4 months. "There are many factors—altitude, soil, precipitation, exposure, and drainage—which cause a variation of forage plants, their growth and density, even upon limited areas. By far the greater portion of the Payette Forest is timbered brush land, approximately 90 per cent of it being classed as forest. It is all classed as summer grazing land."

**Pend Oreille Forest:** Precipitation, 3 stations, 28.8 inches; elevation, 1,665 to 2,380 feet; carrying capacity, 64 to 80 cattle, 3 to 4½ months; 100 to 160 sheep, 3 to 4½ months. "Grazing in this forest is in its infancy, although we are just about stocked. Considerable cattle range is on mountain meadows, and in such localities the carrying capacity is somewhat greater than indicated by the figures above, which represent average conditions for the entire range."

**St. Joe Forest:** Precipitation, 6 stations, 41.0 inches; elevation, 2,155 to 3,735 feet; carrying capacity, 8 to 10 cattle, May 1 to September 30; 125 to 160 sheep, June 1 to September 30. "The above figures are based upon the fact that there are areas within the boundaries of various stock allotments which are unsuited for grazing purposes of any kind. Northern Idaho is not normally a grazing country, and were we to consider the carrying capacity of all mountain and timber lands in northern Idaho the number of acres necessary to support either

sheep or cattle would be much greater than the figures shown above."

**Salmon Forest:** Precipitation, 3 stations, 9.5 inches; elevation, 4,040 to 5,300 feet; carrying capacity, 14 cattle and horses (season not given); 75 sheep for 5 months. "Much of the grazing land in this forest will not carry more than 50 sheep or 9 head of cattle or horses per square mile during a season of 5 months. But we have many small areas that will easily carry 200 head of sheep or 40 head of cattle or horses per square mile for the same season. From the best information available we estimate that the average for the forest is approximately 75 sheep or 14 cattle and horses per square mile."

**Sawtooth Forest:** Precipitation, 5 stations, 18.8 inches; elevation, 5,347 to 6,200 feet; carrying capacity, 60 cattle, 320 sheep, June 1 to September 30. "On the open forest range 3 acres is necessary to support a sheep and from 8 to 10 acres for a cow. This means the entire range, including waste land and timbered areas containing but little feed. On open country producing a first-class stand of forage probably one and a half acres would be sufficient to support a sheep."

**Selway Forest:** Precipitation, 2 stations, 31.8 inches; elevation, 1,397 to 4,000 feet; carrying capacity, 60 cattle and horses, 300 sheep and goats, summer range. "Horses and cattle demand a different class of range from sheep and goats, the former preferring a strictly grass range, while sheep prefer weeds, and goats, brush."

**Targhee Forest:** Precipitation, 5 stations, 21.1 inches; elevation, 5,100 to 6,440 feet; carrying capacity, 60 cattle and horses, 300 sheep, May 1 to October 31. "Capacity varies greatly. Some grazing units will support 125 head of cattle to the square mile for a 6-month period, while there are sections that will not support more than 25 head, due to the fact that considerable land throughout the forest supports but little forage and is classed as waste range."

**Weiser Forest:** Precipitation, 7 stations, 22.6 inches; elevation, 2,200 to 5,025 feet; carrying capacity, 20 cattle and horses, 80 to 90 sheep. Grazing season, low range (cattle and sheep), March 1 to December 15; high range (sheep), April 1 to November 30. "On the Weiser Forest there is more waste land and land with lower forage value within the sheep range than within the cattle and horse range. This accounts for the low ratio. This is not good range for the dry summer months. From the middle of June to the last of September stock should be on higher green feed."

Averaging all the above forest areas in Idaho with an average annual precipitation less than 15 inches, we find that the carrying capacity is 32 head of cattle and horses and 240 sheep and goats for each square mile.

The forests where the average precipitation is between 15 and 25 inches, the carrying capacity averages 37 cattle and horses and 178 sheep and goats. Where the precipitation is over 25 inches, the forests average 43 cattle and horses and 188 sheep and goats per square mile. In those forests where the average precipitation is between 15 and 25 inches, the summer rainfall is relatively considerably less than during the other seasons as compared with the other areas.

If grouped by the carrying capacity of the forest areas, however, we find that the eight forest ranges grazing an average of 16 head of cattle and horses and 149 sheep and goats have an average annual precipitation of 25.2 inches, while nine areas which graze an average of 61 cattle and horses and 234 sheep and goats receive an average annual precipitation of only 22.8 inches.



Apparently, then, there is little, or no, relation between the grazing capacity of the forest ranges in Idaho and the annual, or even the seasonal precipitation.

In the State of Washington, well-cleared and productive land is too valuable to be used for grazing. In the grazing districts, the carrying capacity varies widely in different localities, depending upon the temperature, rainfall, topography, etc.

On the open range in Benton County in the central-southern part of the State, where the average annual precipitation is only 8 to 12 inches, it is estimated that 10 horses or 14 to 16 cattle per square mile can be carried for the grazing season of 7 months.

On the open range in the Yakima and Wenatchee districts in south-central Washington, where the annual precipitation is from about 11 inches (Yakima district) to about 16 inches (Wenatchee region) it is estimated that a section will carry from 10 to 12 cattle, or 100 sheep during the grazing season of 7 months. On very good range in that vicinity, 125 sheep, or 12 to 15 cattle can be run.

The conditions vary so widely in the different forest reserves and even in different parts of the same reserve in this State, that much depends upon experience and judgment of the men in charge.

In the Colville Forest Reserve, where the annual precipitation averages 17 to 22 inches at the lower altitudes, they calculate 40 acres for one horse, or 30 acres for one head of cattle for the season from May to November, inclusive. This is at the rate of 21 cattle to the square mile. Sheep need about 5 acres per head for 4 months.

In the Wenatchee Forest, where the precipitation is 14 to 18 inches at the lower altitudes, it is estimated that a section fully covered with edible vegetation would graze 200 sheep, or 20 to 25 cattle for the grazing season of 4 months. But as no such extensive areas are found, the stock allowed varies from 5 to 25 acres per sheep and 25 to 70 for 1 head of cattle.

A rough estimate for the Wenaha Forest, where the precipitation is 25 inches, a section will support 112 sheep or 28 cattle, or 22 horses for the grazing season of normally 7 months for cattle and horses and 4 months for sheep.

The Chelan Forest is very rugged, and while there are places where 1 acre would graze a sheep, there is no feed in the larger part of the reserve. A conservative figure for the good range is 10 acres for 1 head of cattle or 7 or 8 sheep. The rainfall for the lower altitudes is 12 to 25 inches.

In the Puget Sound country, where the average annual precipitation is 35 to 45 inches, the best subirrigated cleared bottom land properly cared for will maintain at least 1 cow per acre, thus surpassing the condition in the bluegrass country in Kentucky with an equivalent rainfall.

The seasonal distribution of the rainfall seems to be of more importance in California than the average annual fall in considering the relation to grazing. In one section of the Santa Barbara National Forest in southern California the rainfall in 1918 was about 21 inches, but instead of being well distributed through the winter months it did not come until February. It was not followed by good spring and early summer rains; as a result ranges carried only about one-third as much stock as usual. A little more than one-half as much rain well distributed would have given far better results.

In the Cuyama Valley watershed, on the north side of the coast ranges, the average rainfall is only about 12 inches; but because of summer thunderstorms there is as good grazing as on the south side, where the rainfall averages 18 to 20 inches. To produce the best grazing conditions, precipitation must occur early in the fall and then at intervals through the winter and spring. Late spring rains increase the foothill feed. Heavy winter snowfall in the higher mountains increases the feed in the higher pastures.

Foothill ranges in northern California carry from 32 to 50 head of cattle per section for the winter and spring seasons only. From Fresno south the foothill ranges on the east carry from 32 to 40 head per section for the year-long season.

In the western portion of the Trinity Forest, where the rainfall is about 60 inches, the better class of grazing lands carry from 25 to 30 head per square mile. On the east side, where the rainfall averages about 42.5 inches, it requires from 40 to 70 acres of grazing land per head, which amounts to some 10 to 16 head per section, including lands of all types. In addition to the heavy rainfall received by the lands on the west they are also subject to fog during the greater part of the year.

In general, in many parts of the State, where the rainfall averages from 12 to 18 inches a year, the supporting value of the range is about 1 beef animal to each 12 to 15 acres of land, or at the rate of from 43 to 53 per square mile.

In central and northern Nevada about 11 head of cattle and 28 sheep are pastured on a square mile of range grasses. The grazing season is from April 1 to November 15. The average annual precipitation for the areas considered is close to 10.5 inches. The average precipitation, mostly in the form of snow, during the three winter months is about 3.50 inches. While much of the water from this snow flows into streams and is used for irrigation, a considerable amount furnishes moisture for grasses at lower elevations during the first part of the summer and at higher elevations during the latter part and in early fall, when the rainfall is usually light.

While cattle and sheep do not feed upon the same areas, a flock of sheep is often pastured on a range not far from a range used for cattle. Frequently one side of a mountain will be used as a sheep range and the other side for cattle. Hence the number indicated per square mile includes both cattle and sheep.

The period covered by stock on the winter ranges in the southern half of Nevada extends from about November 1 to April 15. The annual precipitation on these winter desert ranges is from about 5 to 7 inches, while the stock grazed per square mile averages about 6 head of cattle and 24 head of sheep.

In the tables following an attempt has been made to summarize the data given above into averages. We recognize the fact that these are applicable only in a very general way, but can be used in the absence of more definite experimental and observational data.

#### RELATION BETWEEN PRECIPITATION AND THE GRAZING CAPACITY OF RANGES.

TABLE 1.—*Arizona, New Mexico, Texas, and Oklahoma, where grazing is mostly all the year.*

Annual precipitation:	Cattle per square mile.
0 to 5 inches.....	0
5 to 10 inches.....	9
10 to 15 inches.....	15
15 to 20 inches.....	24
20 to 25 inches.....	32

TABLE 2.—*In the Great Plains States north of Oklahoma, where there are usually periods of considerable length in the wintertime when grazing is not possible.*

Annual precipitation:	Cattle per square mile.
10 to 15 inches.....	19
15 to 20 inches.....	38
20 to 25 inches.....	76
25 to 30 inches.....	265
30 to 40 inches.....	409

TABLE 3.—*In the central and upper Rocky Mountain and Pacific States, mostly summer ranges, the period of grazing, varying from 3 to 7 months, depending upon the location.*

Annual precipitation:	Cattle per square mile.
5 to 10 inches.....	20
10 to 15 inches.....	28
15 to 20 inches.....	47
20 to 25 inches.....	63
25 to 30 inches.....	97

The greater grazing capacity with the lighter rainfall amounts in the first part of Table 3, as compared with Table 2, is undoubtedly explained by the shorter grazing period in the Rocky Mountain States. On the other hand, the smaller capacity with the heavier rainfalls in the last part of Table 3 as compared with Table 2 seems to be because the regions of heaviest rainfall in the Rocky Mountain States are at the highest elevations where the country is very rough and the available grazing areas small as compared with the Great Plains territory.

The ratio between the number of sheep that can be grazed as compared to cattle as given by different men

varied between 14 and 2 to 1. The average is 7 sheep to 1 head of cattle, and this is the ratio that was used in changing the number of sheep grazed into terms of cattle.

In the following table all of the available data from the Great Plains westward are averaged together after correcting for the period of grazing. That is, if the grazing period is only 6 months, the grazing capacity as reported is divided by 2. If it is only 4 months, the capacity figures are divided by 3.

TABLE 4.—*Relation between the annual precipitation and the grazing capacity of ranges from the Great Plains westward (not including California).*

Annual precipitation:	Cattle grazed per square mile.
0 to 5 inches.....	0
5 to 10 inches.....	8
10 to 15 inches.....	14
15 to 20 inches.....	20
20 to 25 inches.....	43
25 to 30 inches.....	66
Over 30 inches.....	138

While Table 4 may represent the theoretical grazing capacity of ranges for all-the-year grazing, it is not so reliable as the preceding tables, which show averages for the actual grazing that is taking place under different rainfall amounts and for such periods as the season will allow.

The author wishes to give due credit for valuable data furnished by the field officials of the Weather Bureau and the Forest Service.

#### NEW AEROLOGICAL APPARATUS.<sup>1</sup>

By S. P. FERGUSON, Meteorologist.

[Weather Bureau, Washington, D. C., July, 1920.]

##### SYNOPSIS.

The height to which a balloon will rise depends primarily upon the ratio of the lift to the weight carried. The large rubber balloons of either the Assmann or Paturel type required to lift the meteorographs heretofore employed in aerological investigations are costly, and doubtless this circumstance has limited the use of balloons-sondes. An investigation of the methods and requirements of aerology has led to the production of a new meteorograph of very simple construction, important parts of which can be made economically in quantity. The scales, particularly that of the pressure-element, are wider than those of other instruments of the kind, the various operations of preparation and reading the records have been simplified, and the weight is less than one-third that of the next lightest instrument that has been used with balloons-sondes.

One or two small pilot balloons, costing but one-tenth as much as the Assmann balloons, can lift the new meteorograph, and since the pilot balloons are of better quality the heights attained should be greater than those now possible with the larger balloons and heavy equipment.

An experimental engraving meteorograph and a temperature-element without pivots, suitable for use with the Goddard rocket or in other apparatus are described in order to suggest the direction of further study and experiment.

##### INTRODUCTORY.

The maximum height attainable by a balloon depends primarily upon the relative density of the gas in the balloon and that of the air, the ratio of the weight to the total lift at the ground, leakage, differences of temperature, and the material of which the balloon is composed. The maximum height, or "ceiling", of a balloon of rigid materials (silk, paper, goldbeater's skin, etc.) may be determined approximately by the degree of inflation required to raise it from the ground. If it will rise when one-half, one-fourth, or one-eighth

full, and so on, the maximum height will be where the atmosphere is one-half, one-fourth, or one-eighth, etc., as dense as it is at the ground. Obviously, even if it is made of very light material, such a balloon must be very large if great heights are desired; and during the first campaign with balloons-sondes, the French experimenters, considering all circumstances, placed the practical limit of the method at 30,000 meters, if a balloon whose capacity was 5,000 cubic meters were used. Up to 1902 the capacity of the paper and silk balloons used by Teisserenc deBort and Assmann was about 500 cubic meters, the excess lift about 140 kilograms, and the average and maximum heights attained, about 8,000 and 18,000 meters, respectively.

The Assmann expanding balloon, introduced in 1902, revolutionized aerological exploration, for, with a sealed rubber balloon containing but 6 cubic meters of hydrogen, the average height attained has been between 12,000 and 15,000 meters and the maximum 35,000, or almost twice the heights previously accomplished by rigid balloons. The highest ascension in the United States, by Mr. Sherry, then of the Weather Bureau, is particularly noteworthy for the reason that trigonometric observations of altitude were made at two stations up to the highest point reached (32,000 meters).

The most important advance in the direction of economical experimenting has been made by Mr. W. H. Dines, whose baro-thermograph weighs but 48 grams and can be lifted by a small pilot balloon. Time is not recorded by this instrument and progressive changes of condition must be determined from frequent ascensions.

The heights attained by the Assmann balloons have been very variable, chiefly because of the variable

<sup>1</sup> Presented in large part before the American Meteorological Society, Washington, D. C., April 22, 1920.